UWB Printed Antenna for Medical Applications

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***Abstract*— This paper presents a design of an ultra-wideband (UWB) transparent microstrip patch antenna with high performance using polyimide as a substrate and copper as a conductors to be applicable in the medical field. The antenna is designed to resonate at lower frequency bands as much as possible based on the application which is skin cancer detection. The characteristics of the antenna is analyzed by using the Computer Simulation Technology (CST) software at frequency range from 100GHz to 20THz. The proposed antenna has broad bandwidth (BW), high gain and radiation efficiency.**

Key words : Ultrawideband; Bandwidth; Computer Simulation Technology.

I. INTRODUCTION

The terahertz wave refers to as an electromagnetic wave that propagates within the frequency range of 0.1 to 10 THz. One of the unique features of the terahertz radiation is its sensitivity to polar substances, such as water and hydration state. This feature provides a better contrast for soft tissues than x-rays. Additionally, its non-ionizing radiation makes it safe for biological imaging [1 - 3]. Furthermore, the existing methods for cancer detection using Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) are expensive, which limits the frequency of its usage. Hence, this can result in a delay in diagnosing [4].

An important antenna characteristic for microwave imaging application is the wideband frequency. It has been shown that the resolution of the reconstructed image is affected by the incident wave bandwidth and its center frequency [5]. Thus, an ultra-wideband (UWB) antenna, finds its application in the biomedical field. An antenna with a fractional bandwidth of 20% or more is considered as the wideband antenna. Whilst, an UWB antenna typically has a fractional bandwidth of 50% or more [6]. There has been growing interest in UWB antennas for microwave imaging. More specifically, a major application of UWB systems is in microwave imaging of the human body for cancer detection [7].

The growth of research activities in the field of microstrip patch antenna is driven by its light weight, smaller in dimension, low profile, ease of fabrication and good omnidirectional pattern. However, the microstrip antenna is known for one of its drawbacks of having a narrow bandwidth, low gain, and relatively large size. Therefore, there has been considerable research interest in the field of microstrip patch antenna aims for size reduction, increasing gain, wide bandwidth, multiple functionalities and impedance matching.

There have been active researches in improving the bandwidth. A straightforward method is by increasing the substrate thickness. However, with an increase of the substrate thickness, causes surface wave power to increase and radiation power to decrease. This resulted in poor radiation efficiency [8]. Thus, there are various techniques presented to provide a wide bandwidth of the microstrip antenna.

By employing dual staircase technique**,** the bandwidth and the impedance matching was improved. This is because the impedance matching of the antenna depends upon type and position of the feed [9]. Stub was another technique presented in order to improve the impedance matching networks [10]. Photonic Band Gap (PDG), Electromagnetic Band Gap (EBG), and Defected Ground Structure (DGS) have been used as a technique to suppress the surface waves [11].

Shorting pins technique is used to reduce the size of the patch. The surface current intensity, surface waves, and the fringing fields can be suppressed as well by optimizing the shorting pins' positions [12].

The effect of low dielectric permittivity on the terahertz transparent patch antenna was presented in [13]. It was found out that the radiation efficiency, the bandwidth, and the gain were improved when using polyimide as the substrate. This is because polyimide has low dielectric permittivity.

The primary goal of this research is to design a THz antenna for medical applications, namely for skin cancer detection. In order to fulfill this aim, some techniques that are able to improve the performance of THz antennas have been used.

II. ANTENNA DESIGN

In an antenna design modification, changing the size of each element changes the characteristic of the antenna. The reason for this behavior is that any changes in an antenna elements

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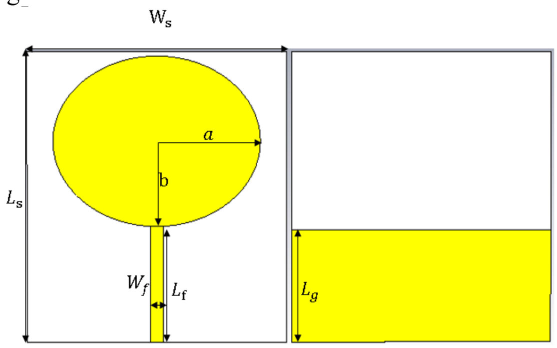
causes the current distribution on the antenna to change. Any changes in the current distribution causes electromagnetic fields around the antenna to change. These changes can affect the radiation pattern, resonance frequency, bandwidth, input impedance, and so on. By analyzing these behaviors it can be demonstrated how variation in each element causes changes in the antenna characteristics. Furthermore, it is possible to find the best antenna performance for a specific application.

After achieve the first and actual dimensions of the antenna using TL method at 1 THz, the dimensions should be optimized to improve antenna's characteristics as can be seen in Fig. 1 and Table 1.



(a) (b)

Fig. 1. The Geometrical Structure of The initial Antenna (a) Front View (b) Back View

TABLE 1. The Dimensions Of The Antenna

Parameters (µm)	L_s	W_s	L_f	W_f	L_g	a	b
Values	75	70	30	3.6	29	28	22

The procedure of the UWB elliptical antenna design modification involves the following steps:

1- Staircase Structure Implementation

In order to improve the BW as well as to suppress the occurrence of stop-bands due to the reduction of the antennas' size, the ground layer is changed to a staircase structure. To do this, two squares are cut from the ground to make staircase shape of the ground. After cutting the staircase structure from the GND layer, the ground layer is divided by two equal parts to meet the UWB TL elliptical antenna [14-16]. Fig.2. and Table 2. demonstrates the staircase structure.

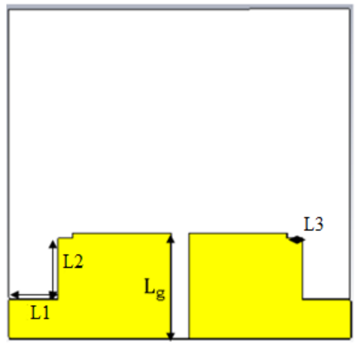


Fig. 2. The Staircase Structure Design

TABLE 2. The Dimensions Of Staircase Structure Design

Parameters (µm)	L_g	L_1	L_2	L_3
Values	24	10	14	3

2-Comb-Like Structure and stub connected to the junction Implementation

In order to have capabilities to increase penetration into skin tissue samples, the antenna supposes to resonate at low frequency band. Therefore, one of the techniques that has been done in order to first remove the stop band at the frequency (related to the total length of the stubs) and second has a resonance at the desired frequency band at the same time keeping the size of the antenna unchanged is by loading the antenna with some stubs which are connected to each other as in Fig. 3.[15] [17].

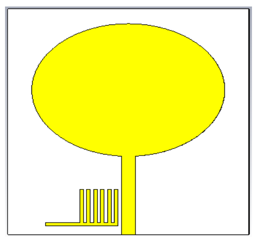


Fig. 3. Comb Like Structure

However, the radiation efficiency has been decreased by this loading and the coupling among these stubs and the transmission line itself made some surface wave which caused that decrement as well. To shift the frequency to lower frequency band and have a resonance in lower band less than 1THz without increasing the size of the antenna, a stub can be connected to the junction between the patch and the transmission line to drive the current into the stub plus the patch. Thus, by connecting the patch to the aforementioned stub, a new resonances at 0.4THz can be made. Fig. 4. shows

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the design of this stub connected to the junction of patch and transmission line.

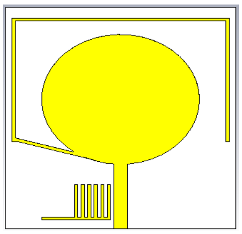

Fig. 4. Stub Connected To Junction.

3-EBG structure and slot on the patch Implementation

Adding the stub to the junction gives a desired resonance at the lower frequency. Besides, shifting the starting point of the lower by more than 20GHz. But, some stop-band are added to the BW after connecting this stub. These stop bands can be reduced and the operation bandwidth can be increased as well by applying some Electromagnetic Band Gap (EBG) and as shown in Fig. 5.

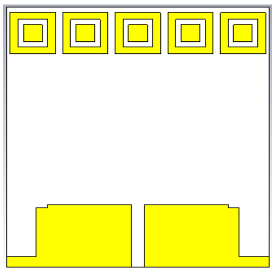

Fig. 5. EBG Structure.

Based on what is illustrated in Fig. 6 about the current density and the current distribution of the patch and the transmission line, three slots are etched from the patch to suppress the current density around the junction and then distributes it to the other parts of the patch.

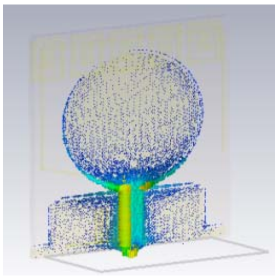

Fig. 6. The Current Density

The dimensions of these slots should be optimized as well. If the slots located near to the junction, the distribution will be done better but it shifts the band to the higher bands. Fig. 7 shows location of the slots on the patch

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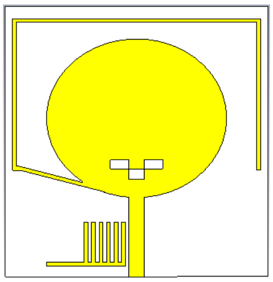

Fig. 7. The Slots Cut From The Patch

4-Shorting Pins Implementation

After checking the results achieved from the proposed antenna, it's tangible that despite of applying the EBG and the slots still there are some stop-bands on the BW. To remove the left stop-bands which has been made due to the surface waves and to suppress these surface waves, the proposed antenna is loaded by some shorting pins. These shorting pins are located based on the current distribution around the stubs and the EBG structures. Fig. 8 illustrates the locations of these shorting pins.

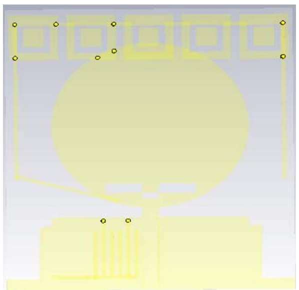

Fig. 8. The Location Of The Shorting Pins

The final prototype of the proposed antenna is shown in Fig. 9. In the final design, the dimension of the ground and the stubs have been optimized again to omit the stop-bands as much as possible.

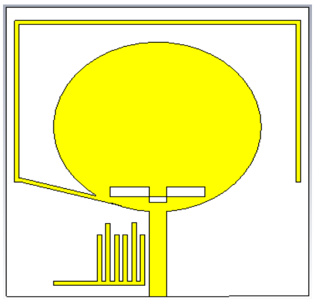

Fig. 9. The Final Design

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III. RESULTS AND DISCUSSION

1-Performance of The Initial Design

Fig. 10 and Table 3 show the return loss and radiation properties results of the initial design of the antenna respectively, which resonates at the frequency range of 0.1-20THz. Moreover, the S_{11} level for UWB initial elliptical monopole transparent antenna is applicable at almost 1.3THZ since it is less than -10 dB and there are two stop-bands though the frequency band. Beside, from Table 3, the radiation efficiency is 6.3% at 0.5THz.

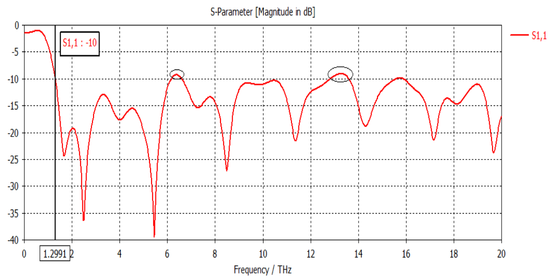

Fig. 10. Reflection Coefficient Of Initial Antenna

TABLE 3 Radiation Properties

Frequency (THz)	Radiation Efficiency (%)	Gain (dB)
0.5	6.3	-7.46
1	77.3	1.1
3	88.2	3.14
5	84.4	3.93
8	82.7	4.72
12	76.8	4.32
14	75.7	5.16
16	70.7	4.89
18	66.8	6.65
20	67.2	5.39

2-Effect of Staircase Structure Implementation

As can be seen from Fig. 11, the BW of the antenna has been increased around 200GHz. Although, there are two slight stop-bands which could be ignored. In the case of BW, it has been fulfilled the BW (UWB) but it's been trying to shift the band to lower part due to meet the lower band necessity.

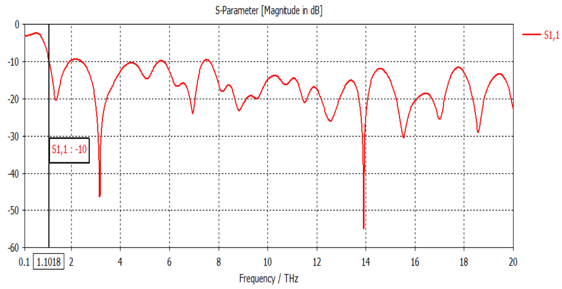

Fig. 11. Reflection Coefficient Of Staircase Structure

3-Effect of Comb-Like Structure and stub connected to the junction Implementation

Afterward, to shift the frequency band to the lower bands, seven stubs have been connected as a comb-like shape to shift the bands to the lower part. After adding these stubs the frequency band has been shifted from around 1.1THz to 1.075THz as well as the stop-band around 2THz has been removed (Fig. 12).

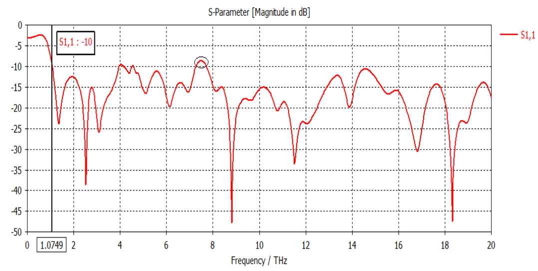

Fig. 12. Reflection Coefficient Of Comb-Like Structure.

The next step of proposed antenna design is applying a stub connecting exactly to the junction of the patch and the transmission line (TL). Thus, the current which has been driven from the feed line (TL) was divided into two parts and another part of this driven current goes through this stub. The length of this stub is related to the resonant frequency that is desired to resonate at it. As can be noticed from Fig. 13, a resonance has been created at 0.4THz after connecting this stub to the junction. Moreover, the BW is shifted by around 40GHz to the lower bands from 1.075THz to 1.036THz.

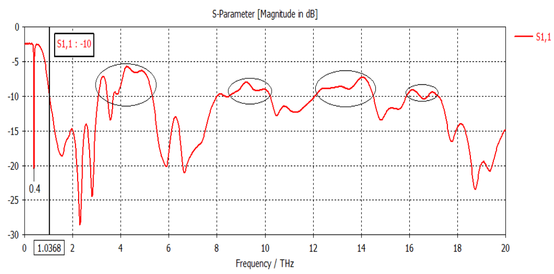

Fig. 13. Reflection Coefficient With Stub Connected To The Junction

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4-Effect of EBG and slot on the patch structure Implementation

In order to remove the stop bands occurred by adding the stub to the junction along with shifting them to the lower part, some rectangular ring Electromagnetic Band Gap (EBG) structures are added to behind the patch upper side of the ground. These EBG structures reduce the surface current and the surface wave created by the last stub and its coupling with the other parts of the resonator.

Based on Fig. 14, the stop-bands around 3.3THz has been almost removed. Furthermore, two resonances have been created at 4.48THz and 5.2THz. The other stop-bands at the higher part of bands (around 14THz and 17THz) are removed as well.

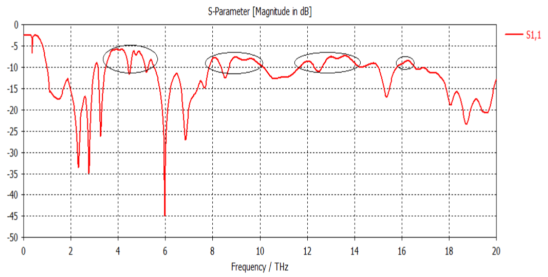

Fig. 14. Reflection Coefficient With EBG Structure

Next step is cutting three slots from the patch. These slots have been cut near the junction to distribute the current from the junction and drive it to the other part of the patch as. This cutting can be considered as a capacitive loading which decreases the current density around the junction. Based on Fig. 15, after cutting the slots the current around the junction drives through the patch better. Thus, the stop-bands' reflection coefficient level is getting lower which is more acceptable.

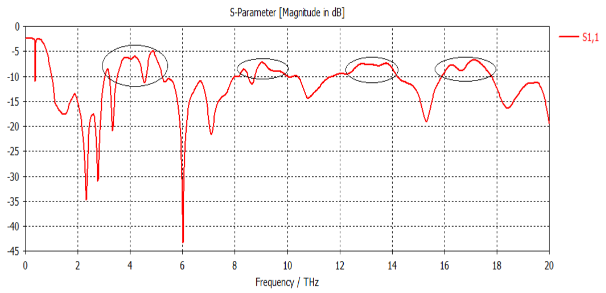

Fig. 15. Reflection Coefficient With The Slots Cut From The Patch.

5-Effect of Shorting Pins Implementation

One of the techniques to load the antenna is loading it by exploiting some shorting pins that connect the resonator to the ground or the other side of the antenna. After checking the current distribution of the proposed antenna around the ground, patch and even the EBG structure; it can be decided where to locate the shorting pins.

As might be perceived from Fig. 16, after adding the pins, the stop-bands have been removed with only two slight stop-bands which could be ignored and the frequency bands has been shifted to lower part as much as possible (until 1.018THz) related to the frequency and the size of the antenna .

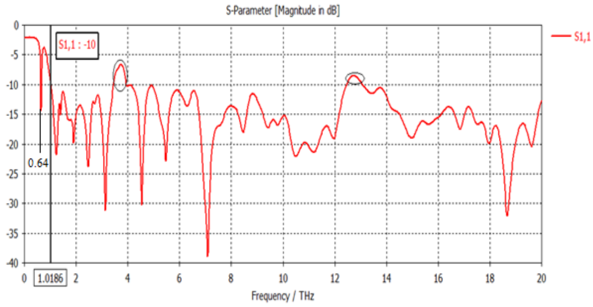

Fig. 16. Reflection Coefficient with shorting Pins.

TABLE 4. Radiation Characteristics with shorting Pins

Frequency (THz)	Radiation Efficiency (%)	Gain (dB)
0.5	13.5	-5.96
1	62.3	0.63
2	70.1	2.63
4	66.6	2.75
6	71.2	3.94
8	64.7	5.79
10	61.7	3.7
12	59.6	3.88
14	58.5	6.25
16	59.7	5.29
18	46.3	4.8
20	51.2	4.89

Table 4 shows the radiation properties of the proposed antenna with material of polyimide and copper (optical). It is showing a higher radiation efficiency and gain for the lower part of the BW.

IV. CONCLUSION

Summing up the entire work done throughout this paper, it is investigations of applying transparent UWB printed antennas for both communication and medical imaging. The antenna was etched on polyimide with permittivity of 3.5 and the

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conductor material is copper (optical) with an evident compact size of 75 x 70 x 3μm^3. Return loss measurements demonstrated that this antenna achieves a resonance at 0.64THz and a good bandwidth for VSWR less than 2 over the frequency band (from 1.018THz to 20THz with only two slight stop-bands which could be ignored).

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